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The QWIP Focal Plane Assembly for NASA's Landsat Data Continuity Mission

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Background

The NASA Landsat program has been in service since 1978 providing thermal imagery of the earth

The data has been used for a wide range of applications including:

- Climate change impact
- Agricultural monitoring
- Mapping heat fluxes from cities
- Monitoring air quality
- Monitoring volcanic activity
- Monitoring the rain forests
- Biomass burning
- Industrial thermal pollution in the atmosphere, rivers and lakes
- Monitoring/tracking material transport in lakes and coastal regions
- Identifying insect breeding areas
- ***Water rights disputes resolution***

Landsat 7 was launched in 1999 with a 5 year mission life requirement

The Landsat Data Continuity Mission (LDCM) is scheduled to be launched in December 2012 to continue the Landsat Program legacy-joint NASA-USGS mission

The Thermal Infrared Sensor (TIRS) is a late addition 10.5-12.5 μm IR imaging instrument

Detector Technology Selection Rationale

Starting in 2004, studies were conducted at Goddard to recommend a detector technology for a thermal IR instrument on the upcoming Landsat Data Continuity Mission.

At that time only HgCdTe and microbolometers were considered. The selection criteria was based on:

- Performance requirements
- Availability
- Delivery schedule
- Cost

During this review it was determined that microbolometers were a more promising detector technology choice over HgCdTe based on cost and delivery schedule, even though technically the HgCdTe was more than adequate. QWIP technology was not considered because insufficient data existed on their longwave, broadband performance (8-12 μm).

The microbolometer-based instrument was pursued for ~3 years and then encountered technical, funding and programmatic issues (while the LDCM kept marching on with the main OLI instrument).

The entire TIRS concept was revisited in 2008 because:

- Performance limitations of microbolometers (time constant, TDI for NEΔT spec, low f/#)
- Severely reduced delivery schedule to start over
- Even more uncertainty to pursue MCT with reduced schedule and severe cost constraints
- Emergence of broad band far IR QWIP technology

Project Overview

1. Design/fabricate a 640 x 512, 10.5-12.5 µm GaAs QWIP with an Indigo 9803 ROIC
2. Design/fabricate a custom silicon carrier board
3. Assemble 3 "Grade A" QWIP hybrids into a Flight Focal Plane Assembly (FPA)
4. Install narrow bandpass filters
5. Perform radiation (gamma, protons, heavy ions) and environmental tests
6. Incorporate Teledyne "SIDECAR" ASIC into control electronics
7. Fully characterize the arrays and the Flight FPA
8. Delivery of a Flight and Flight Spare required by July 2010 (<2 years start to finish)

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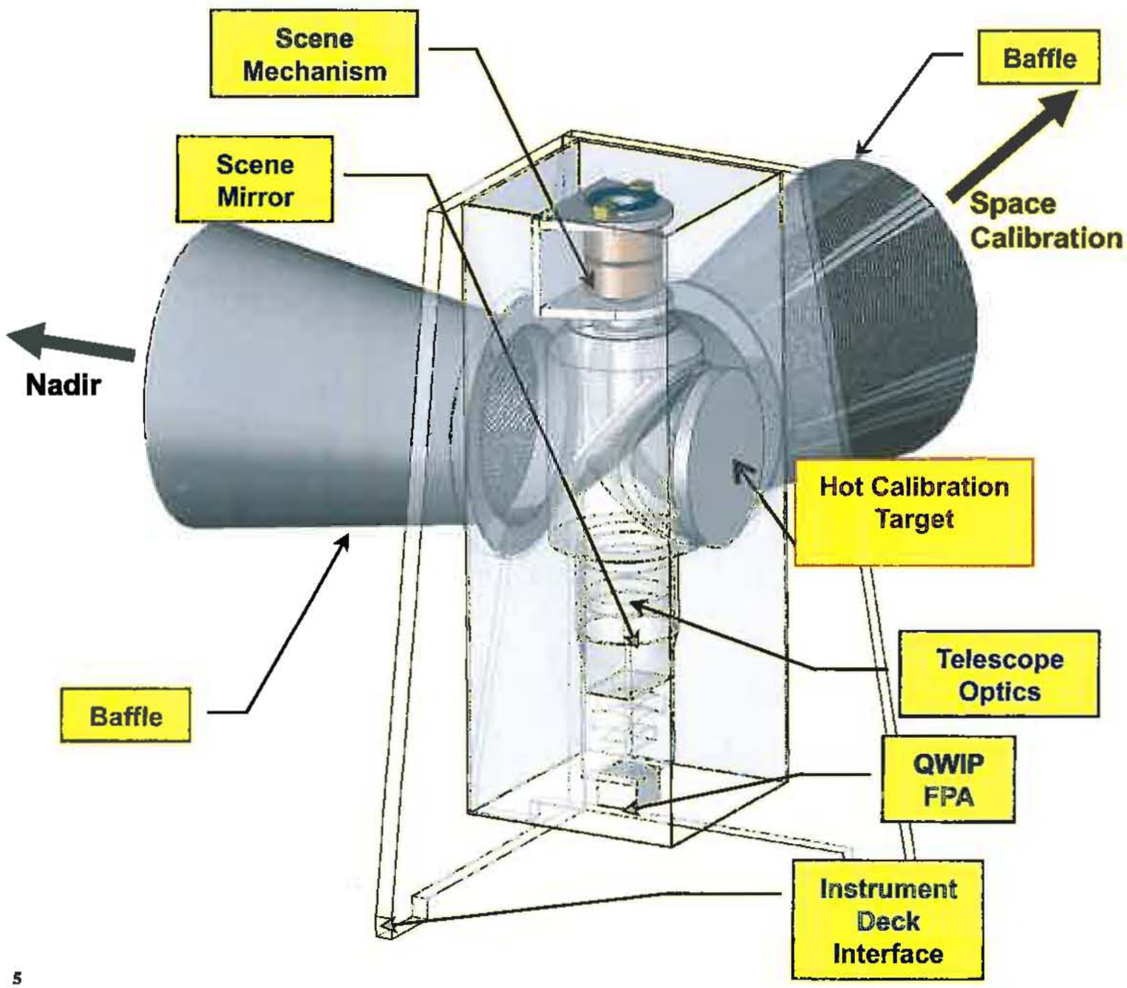
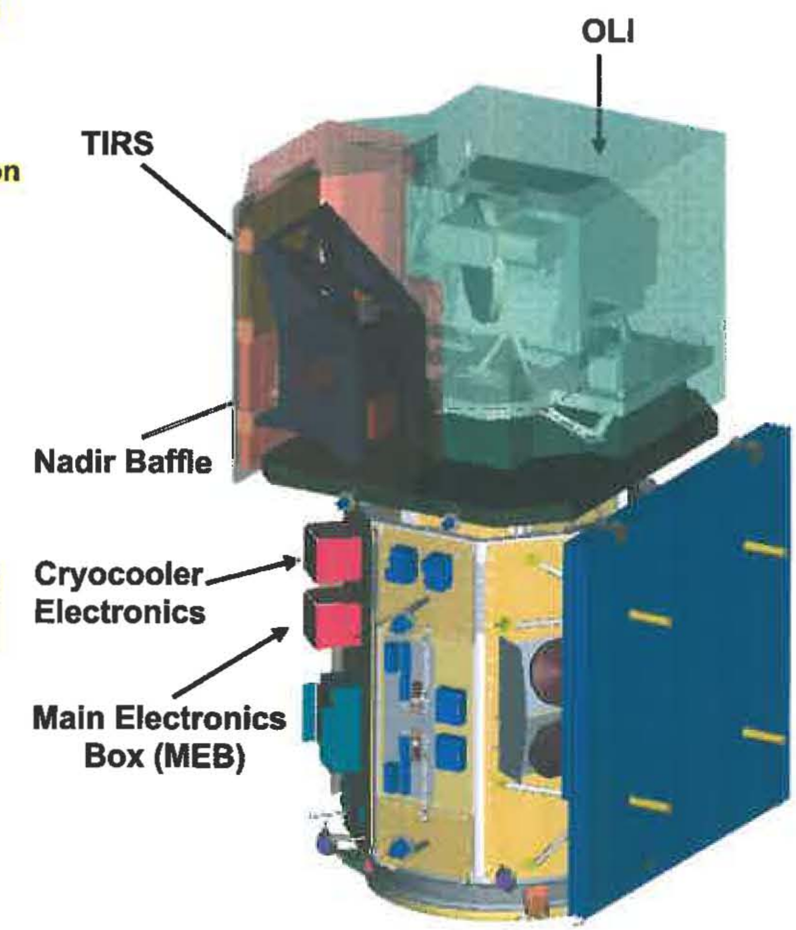
Landsat Data Continuity Mission Spacecraft





TIRS Focal Plane Requirements

-Spacecraft altitude:	705 km
-Across track speed:	7 km/sec
-Two spectral bands:	10.3-11.3μm; 11.5-12.5μm
-NEΔI (320K)	0.059/0.049 $W/m^2 sr\ \mu m$
-Optics (T~160K):	f/1.64
-Pixel size:	25μm x 25μm
-Ground resolution:	$100m^2$/pixel
-Operating temperature:	43K

Within each filter band on each Sensor Chip Array (SCA), the FPA shall provide at least 3 unique pixel rows which can be combined through ground processing so that any combination of 2 rows has fewer that 0.1% of the pixel elements that meet operability requirements for any continuous data collection period up to 44 minutes.

Pixel operability defined as:

-CE and I_D	*At the nominal operating temperature of 43K, the FPA shall have a combination of Conversion Efficiency (CE) and dark current (I_D) such that the predicted NEΔT for either band viewing a 300K target is less than 0.33K.*
-I_D variation at nom. stable operating conditions	<0.2% of mean over 44 min
-CE variation at nom. stable operating conditions	<0.1% of mean over 44 min
-Read noise	<550e-
-Full well capacity	>5Me- (11Me- max.)

-When mounted to the invar baseplate, the photoactive area of the 3 detector arrays shall all be within ± 10.0μm of each other.

-The FPA will survive 40 thermal cycles from ~300K-77K.

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TIRS NEΔT System Requirements

NEΔT ≤0.33K: 300K source; t_{int}=5.5ms; over the entire 10.5-12.3 μm spectral band

$$\mathrm{NE\Delta T} = \frac{\left[I_n^{\ 2}\right]^{1/2}}{S_{\Delta T}}$$

$$I_n^{\ 2} = \mathbf{i}^2_{\text{shot, dark I}} + \mathbf{i}^2_{\text{shot, signal}} + \mathbf{i}^2_{\Delta\text{T,telescope bkgrnd}} + \mathbf{i}^2_{\Delta\text{T,telescope bkgrnd}} + \mathbf{i}^2_{\Delta\text{T,mirror}} + \mathbf{i}^2_{\Delta\text{T,tel optics}} + \mathbf{i}^2_{\text{ROIC read}} + \mathbf{i}^2_{\text{elec, noise}} + \mathbf{i}^2_{\text{A/D noise}} \quad (e^2)$$

$$Q(\lambda) = B/\pi \left[\int_{\lambda_1}^{\lambda_2} \lambda^{-4} \cdot \left(e^{c_2/\lambda \cdot T} - 1\right)^{-1}\right] d\lambda \quad \text{(ph/sec-cm}^2\text{-sr)}$$

$$S_{T_i} = \Omega \cdot t_{\text{int}} \cdot T_{opt} \cdot A_D \cdot CE \cdot Q(\lambda)$$

$$S_{T_i} = \Omega \cdot t_{\text{int}} \cdot T_{opt} \cdot A_D \cdot CE \cdot B/\pi \left[\int_{\lambda_1}^{\lambda_2} \lambda^{-4} \cdot \left(e^{c_2/\lambda \cdot T_i} - 1\right)^{-1} d\lambda\right] \quad (e)$$

$$S_{\Delta T} = (S_{T_2} - S_{T_1})/\Delta T \quad (e/K)$$

$B = 1.88 \cdot 10^{23}\ \mathrm{m}^3/\mathrm{cm}^2 - \mathrm{sec}$

$c_2 = 1.44 \cdot 10^4\ \mathrm{m-K}$

$A_D \cong 6.3 \cdot 10^{-4}\ \mathrm{cm}^2$

$W = p/(1 + 4f/\#^2)$

$T_{opt} = \prod \varepsilon, optic\ trans$

$T_2 = T_1 + 1K;\ (\Delta T = 1K)$

$\Delta\lambda = 1\mu m$

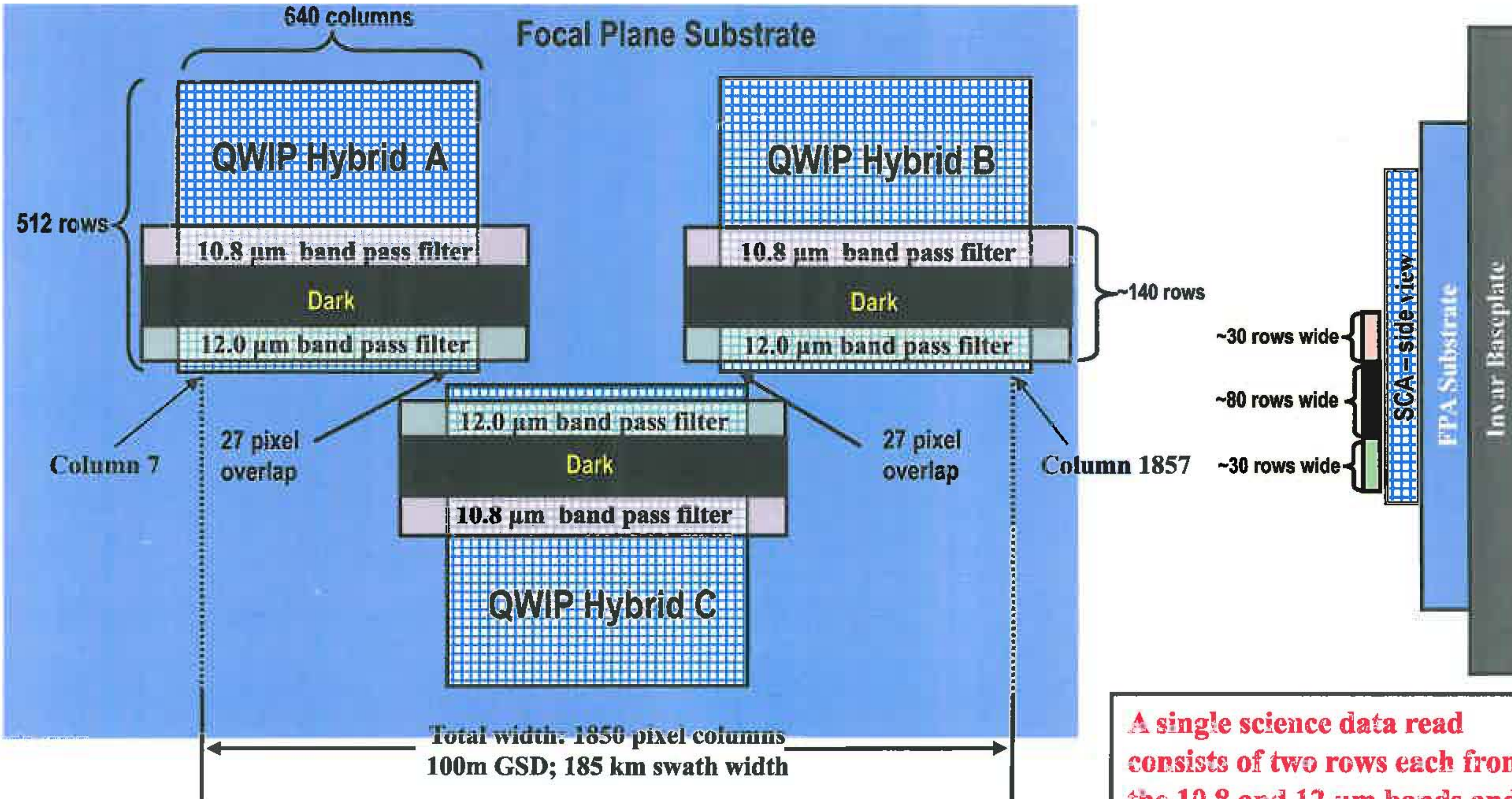
TIRS Nominal Model Parameters

F-number	1.64
Temperature of target	300K
Temperature of QWIP	43K
Detector T stability	0.01K
Background T stability	0.10K
Temperature of optics (K)	180K
Optics T stability	0.10K
Mirror Temperature (K)	293K
Mirror Temperature stability	1K
ROIC read noise	550e
FPE added noise	1,000e
A/D (bits)	12
Integration time	5.5ms
Full well	>5Me

Noise Source	Contribution (e^2)
$i^2_{shot, dark}$	1.32E+05
$i^2_{shot, signal}$	4.17E+05
$i^2_{\Delta T, telescope\ bkgrnd}$	5.88E+05
$i^2_{\Delta T, Idark}$	1.25E+06
$i^2_{\Delta T, mirror}$	9.88E+04
$i^2_{\Delta T, tel\ optics}$	7.15E+02
$i^2_{read\ noise}$	3.03E+05
$i^2_{FPE\ noise}$	1.00E+06
$i^2_{A/D\ noise}$	4.87E+05
$[\Sigma I^2_{source}]^{1/2}$	2.07E+03
SIGNAL (S)	6.29E+03

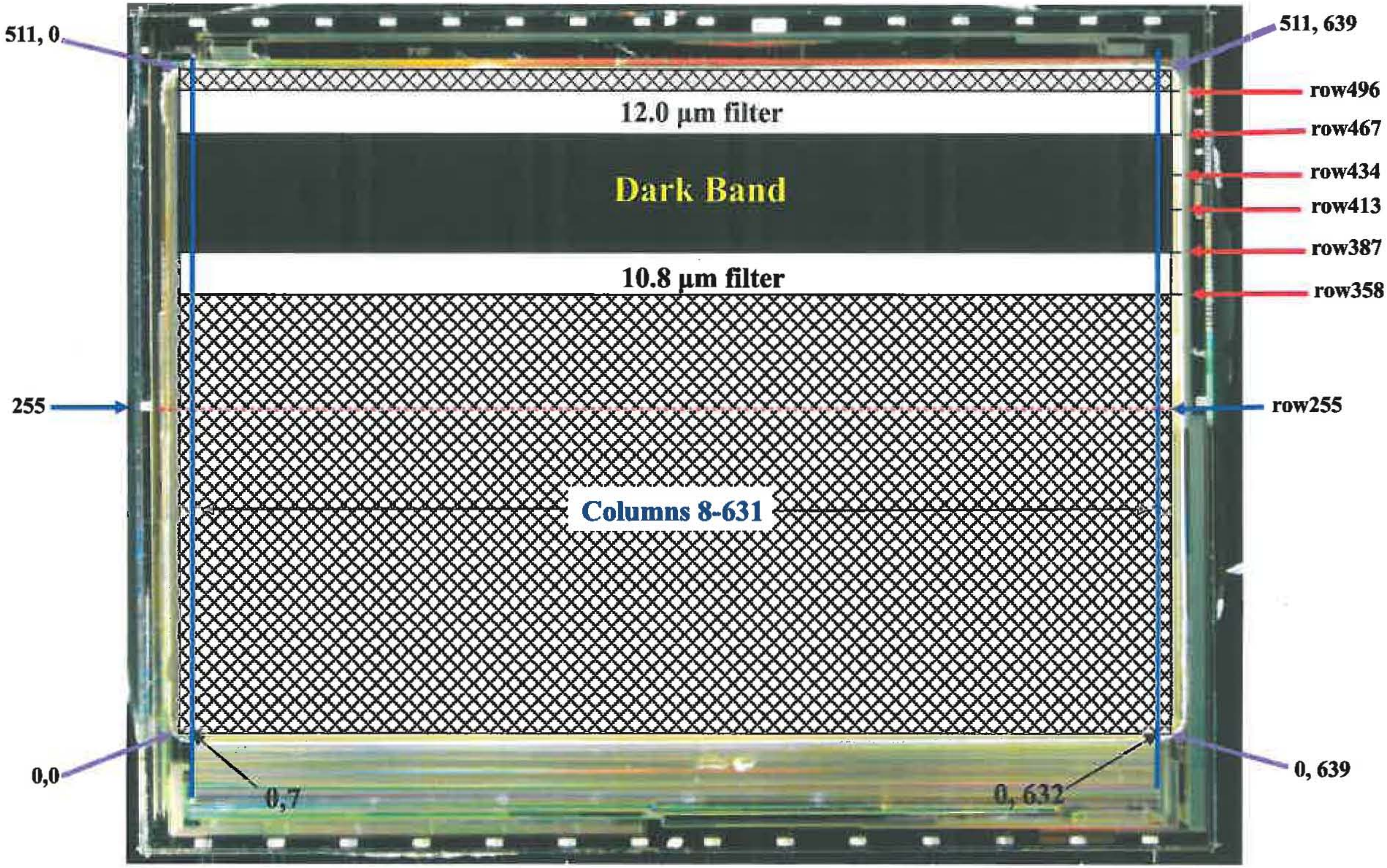
$$NEdT = [\Sigma I_T^2]^{1/2} / S = 0.329K$$

Focal Plane Layout



A single science data read consists of two rows each from the 10.8 and 12 µm bands and 2 rows of dark current data. Each row has 1920 pixels spanning all three SCAs.

Row Identification on QWIP Hybrid



GaAs QWIP Array Fabrication

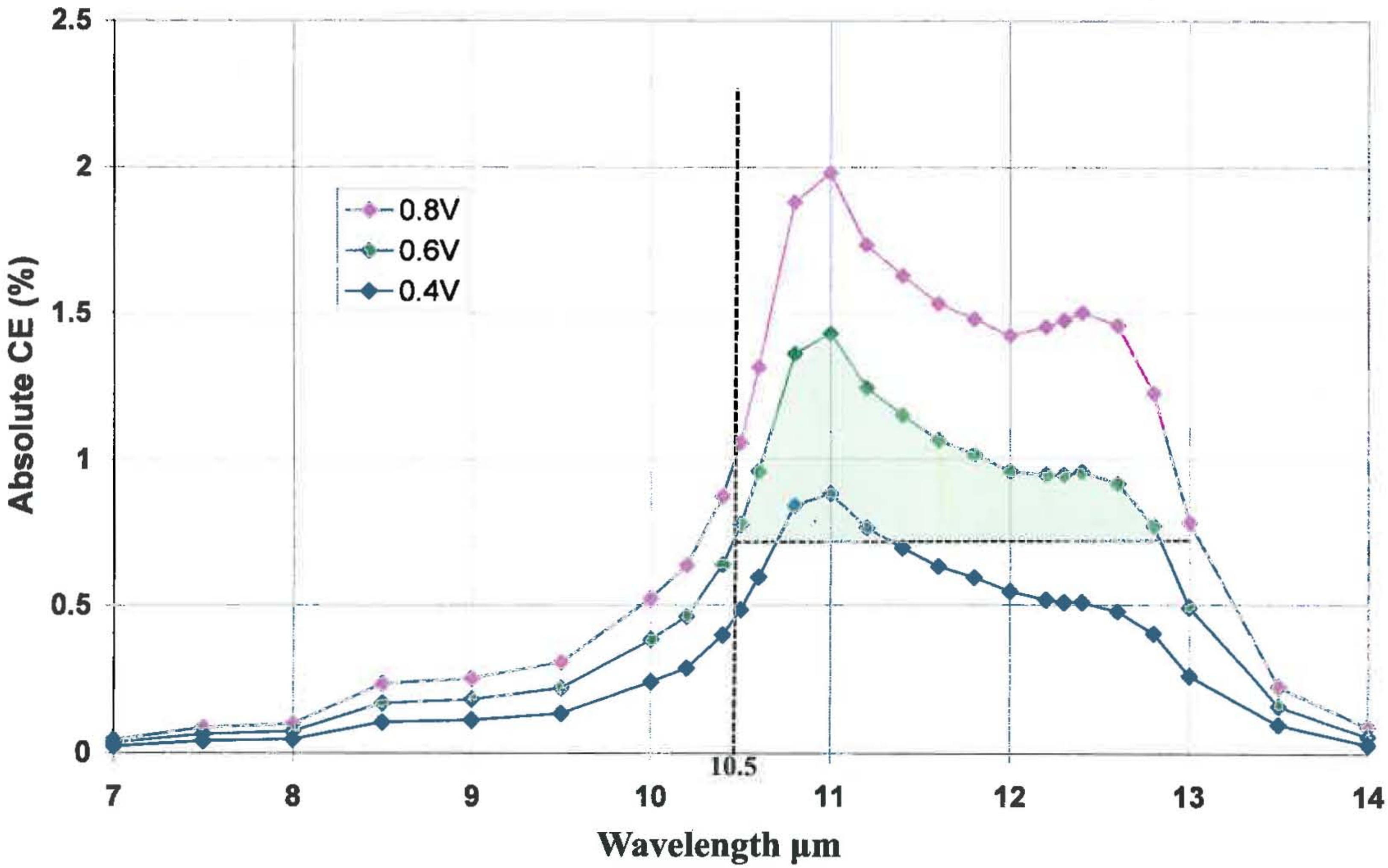
Two parallel paths for QWIP array fabrication and hybridization

1. QWIP arrays fabricated jointly by GSFC/ARL in based on corrugated light coupling mechanism.

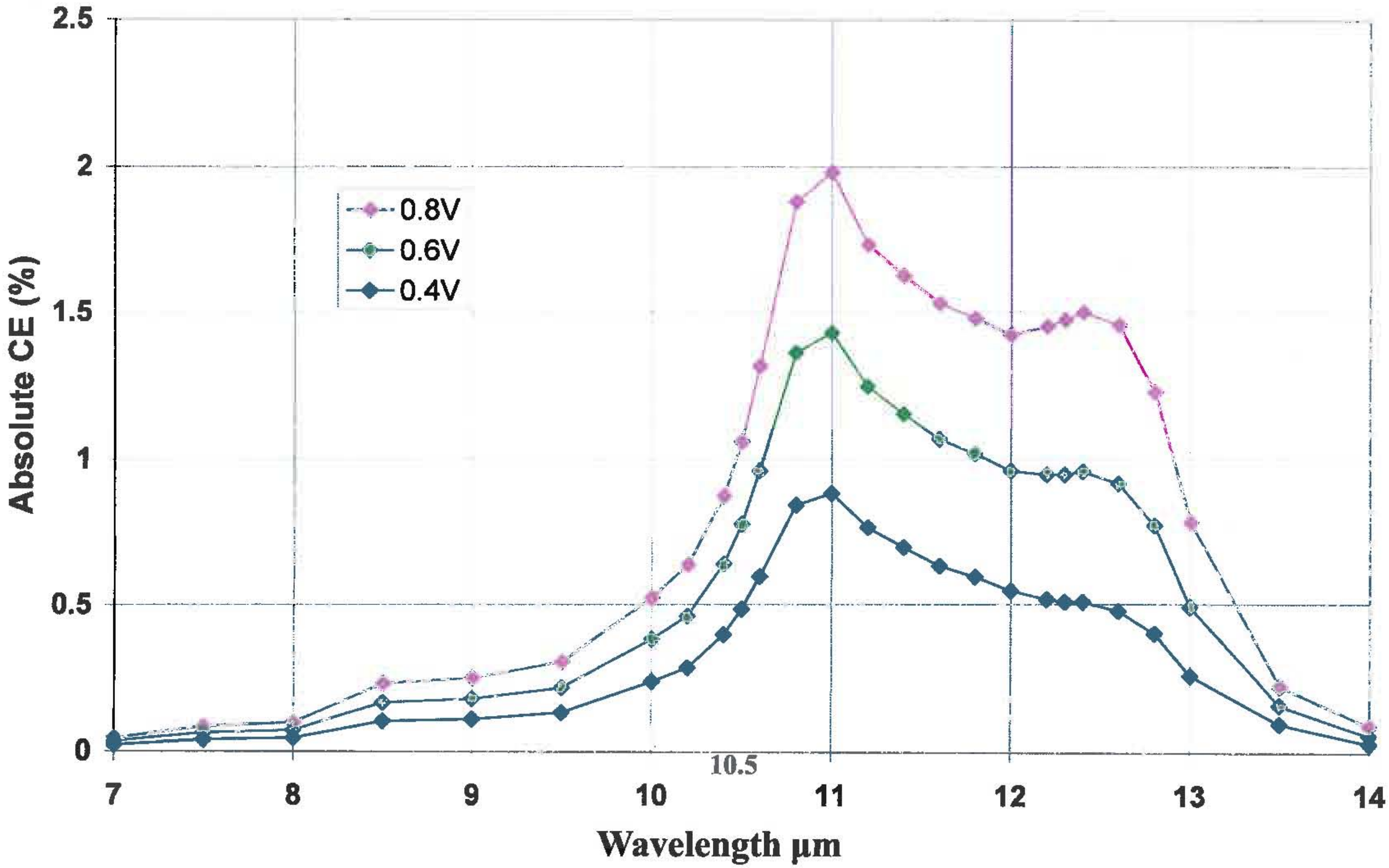
2. QWIP arrays fabricated by QmagiQ, LLC based on a grating light coupling mechanism structure.

Both processes produce similar performing devices

Conversion Efficiency (CE)
(Grating QWIP)



Conversion Efficiency (CE)
(Grating QWIP)



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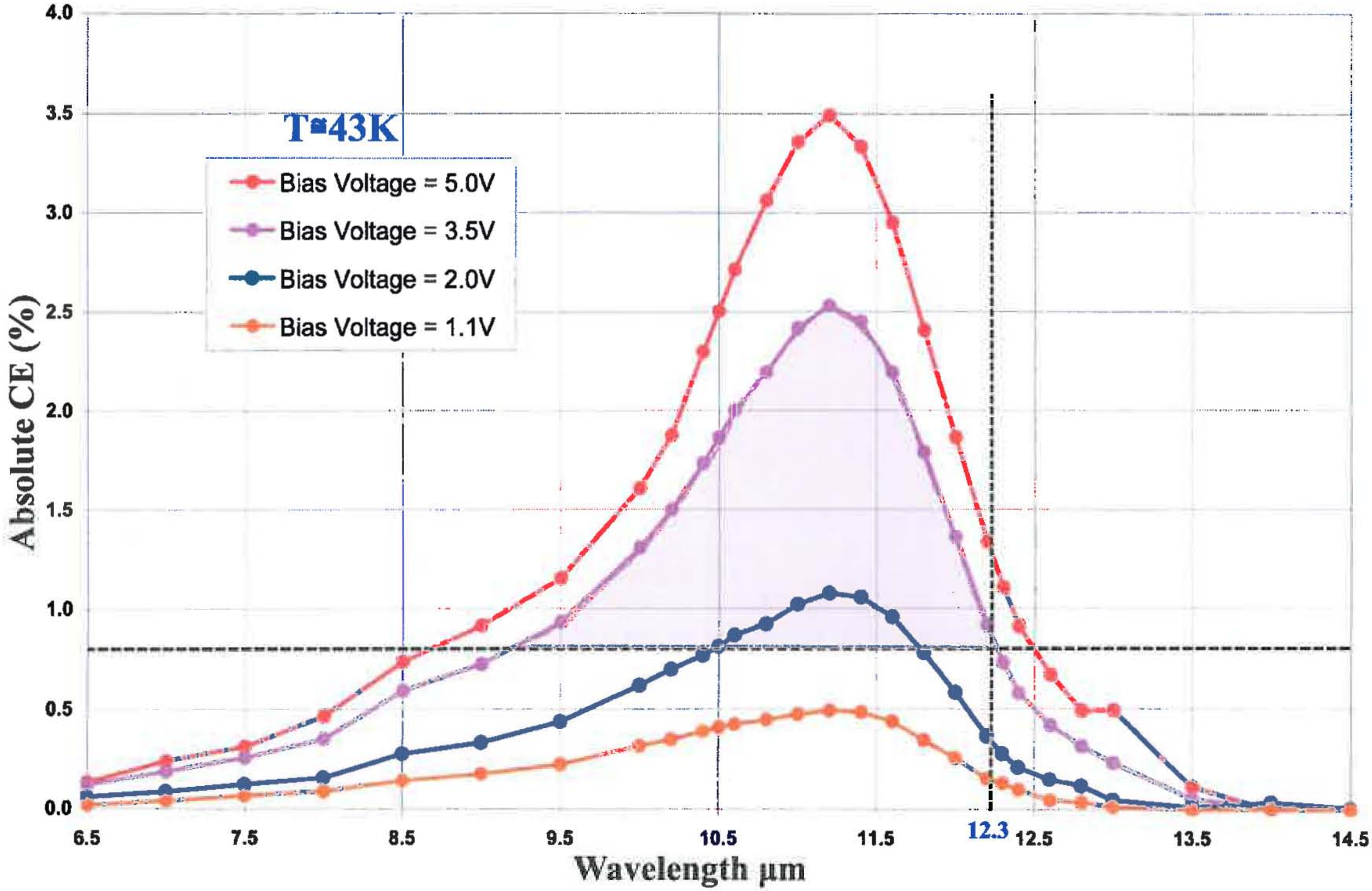
C-QWIP Conversion Efficiency



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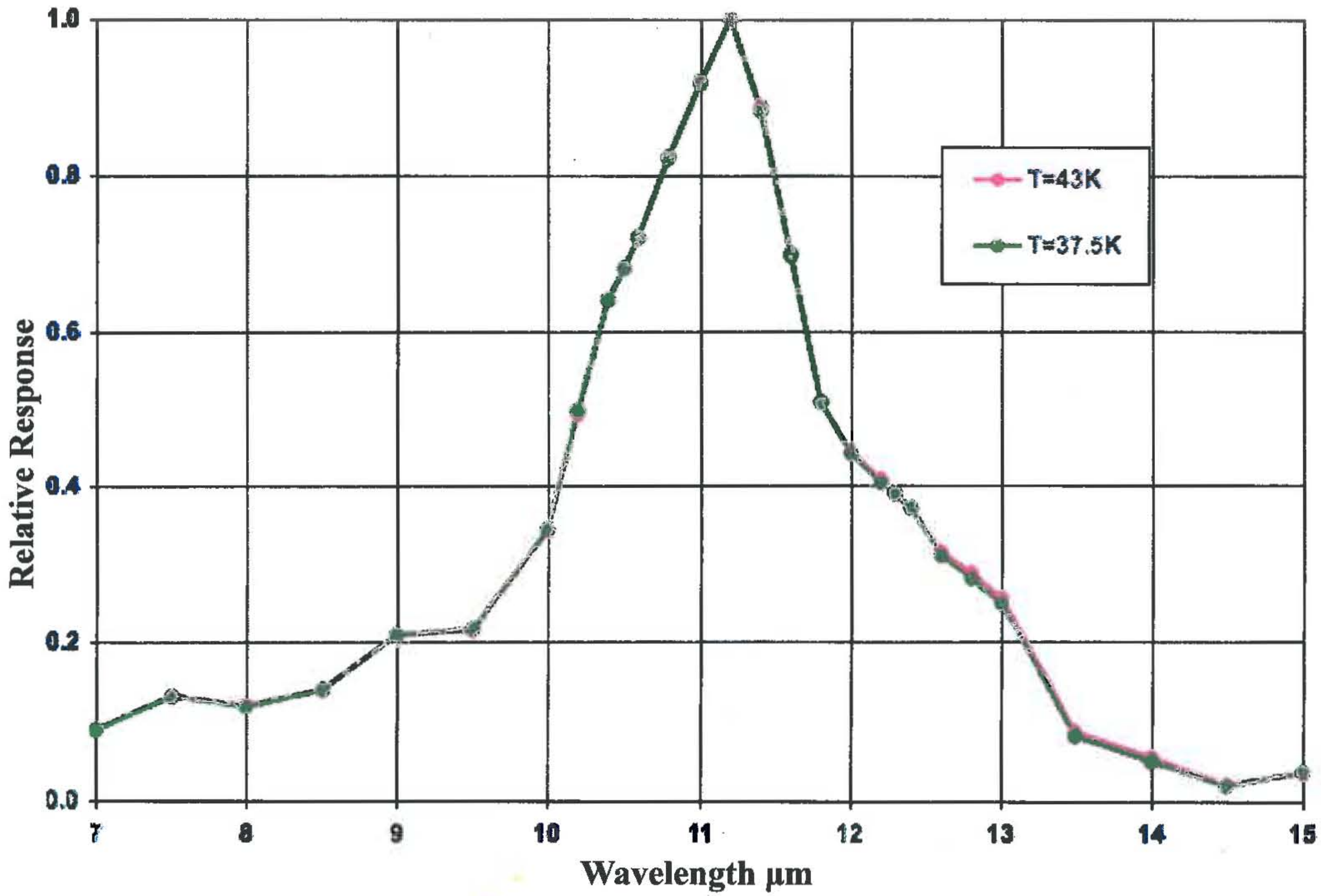
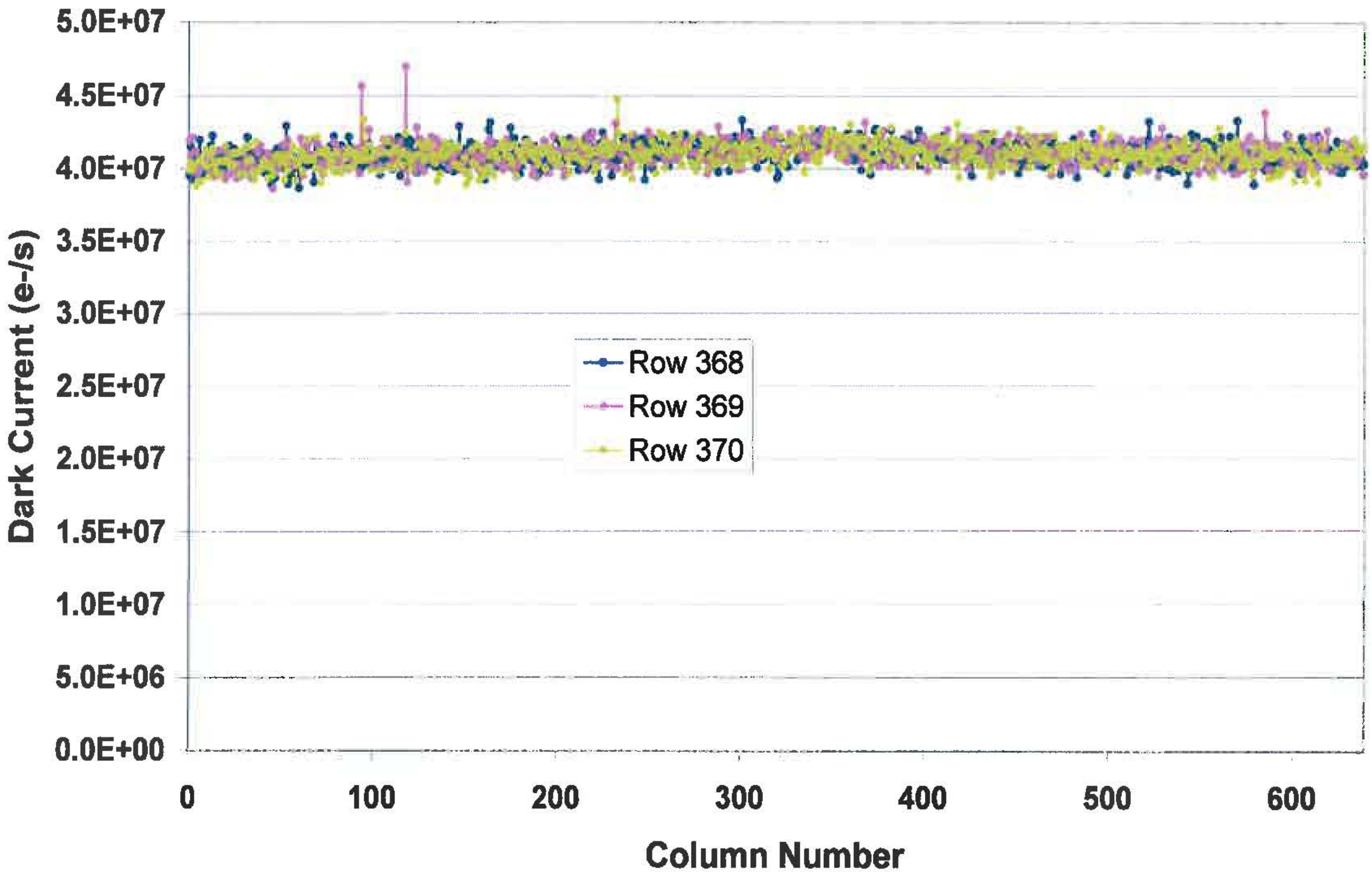
Relative Spectral Response for Two Temperatures
(Grating)

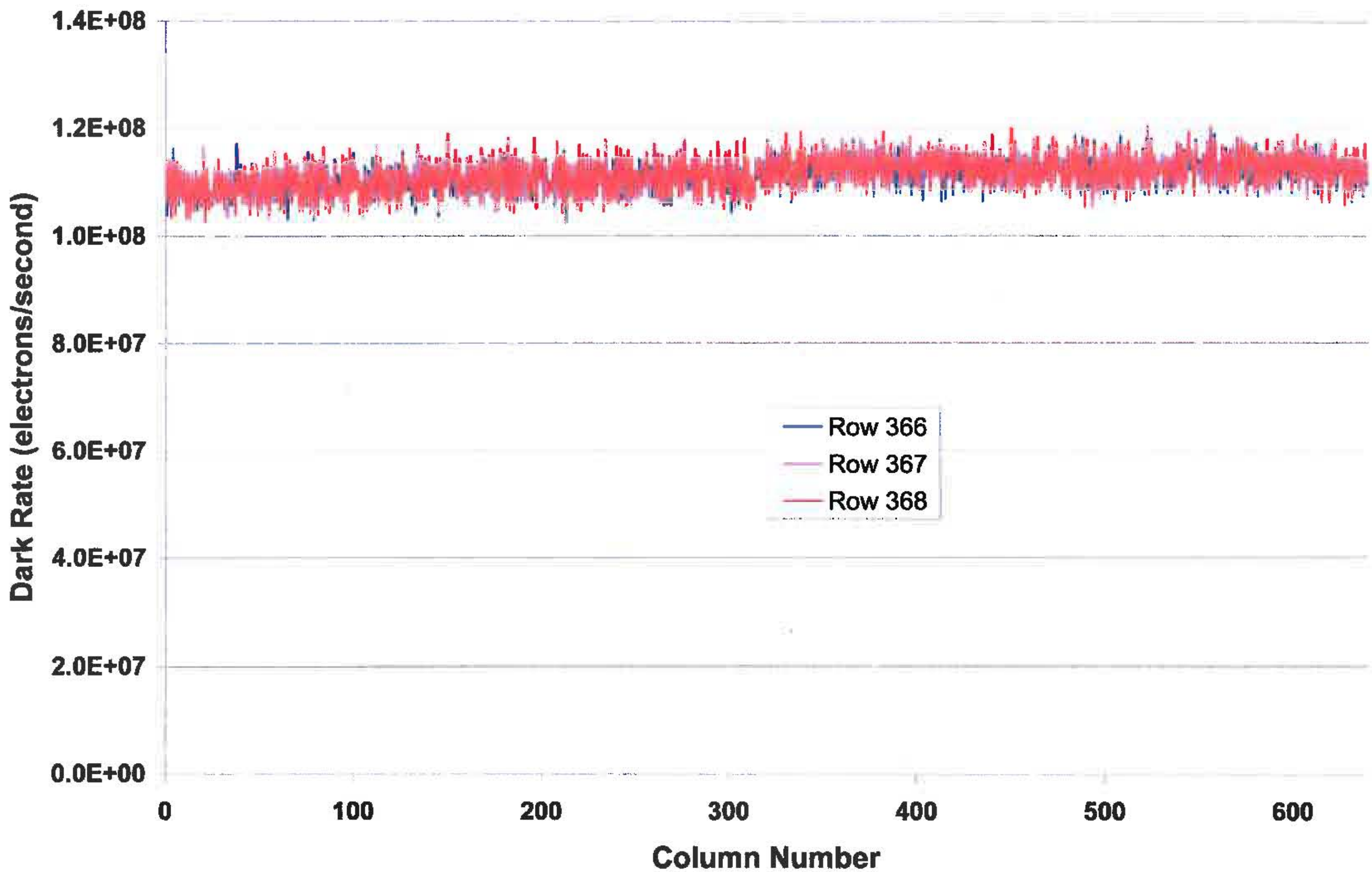


Grating-based QWIP Dark Current Pixel Plot for 3 rows
V_{det}=0.60V; T_{det}=43K



C-Dark Current Pixel Plot for 3 rows

V_{det}=0.60V; T_{det}=43K



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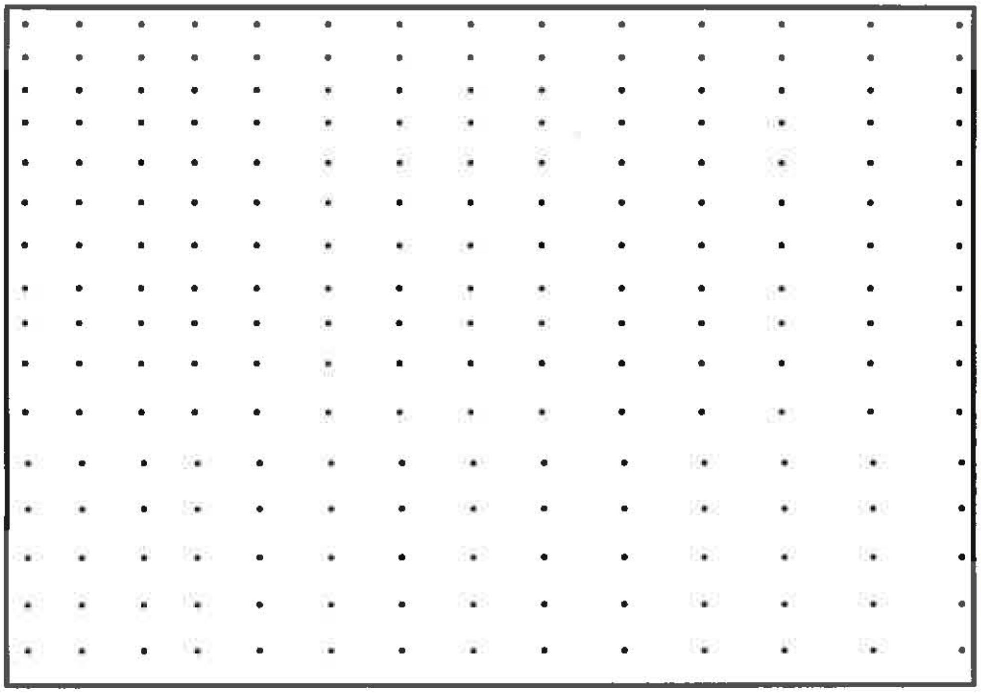
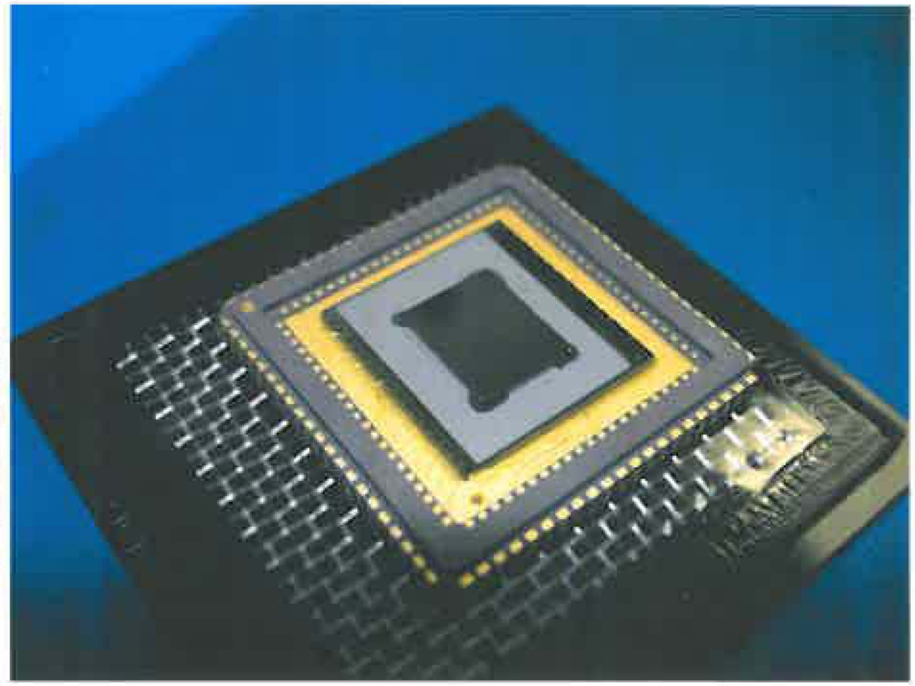
Unthinned C-QWIP Optical Cross Talk (using customized silicon pinhole mask)



Pinhole mask layout



C-QWIP with pinhole mask on top

Each pinhole is 20μm in diameter; spacing starts at 503μm and increments by 4.0μm both horizontally and vertically for each subsequent pinhole. There 18 columns and 16 rows (not to scale).

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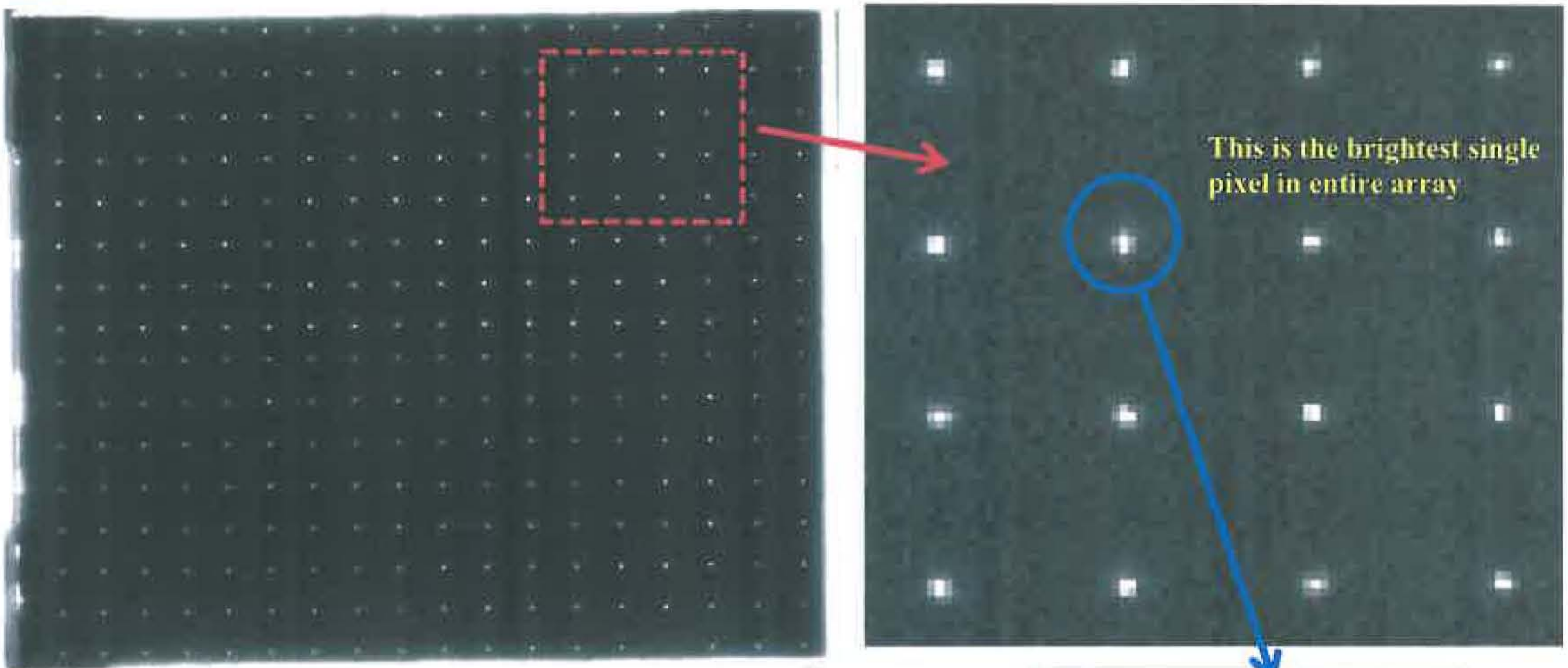
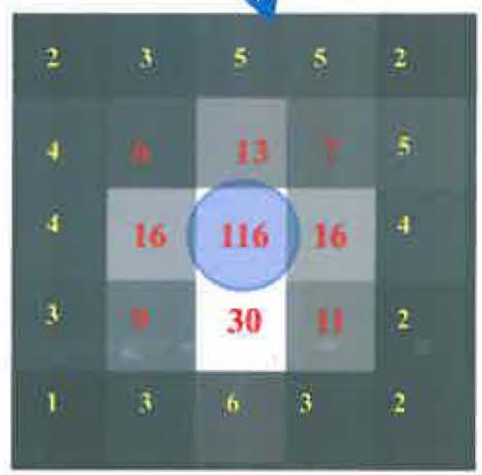
C-QWIP Optical Cross Talk





Pixel pitch ~25μm x 25μm
Diffraction limit (airy disk diameter, D);
$\sin\theta = 1.22\lambda/dn = 13.4^{o}$
$D = 2t\,\mathrm{Tan}\,\theta/2 + 20\mu m = 30.5\mu m$
where,
$\lambda \sim 12.5\mu m$ (LW 50%)
t=thickness of GaAs over active quantum well region ~45μm
d=aperture diameter, 20μm
n=index of refraction for GaAs▪3.3

NEΔT Analysis at T_{Det}=43K

Optimum Bias Conditions, T_{source}=300K

I_D≈1.1E8e/s (C-QWIP); ≈1.4E8e/s (Grating QWIP)

Worst case CE at 12.3μm≈0.8% (C-QWIP); ≈1.5% (Grating QWIP)

<u>SYSTEM</u> NEΔT=0.199K (C-QWIP); =0.167K(Grating QWIP)

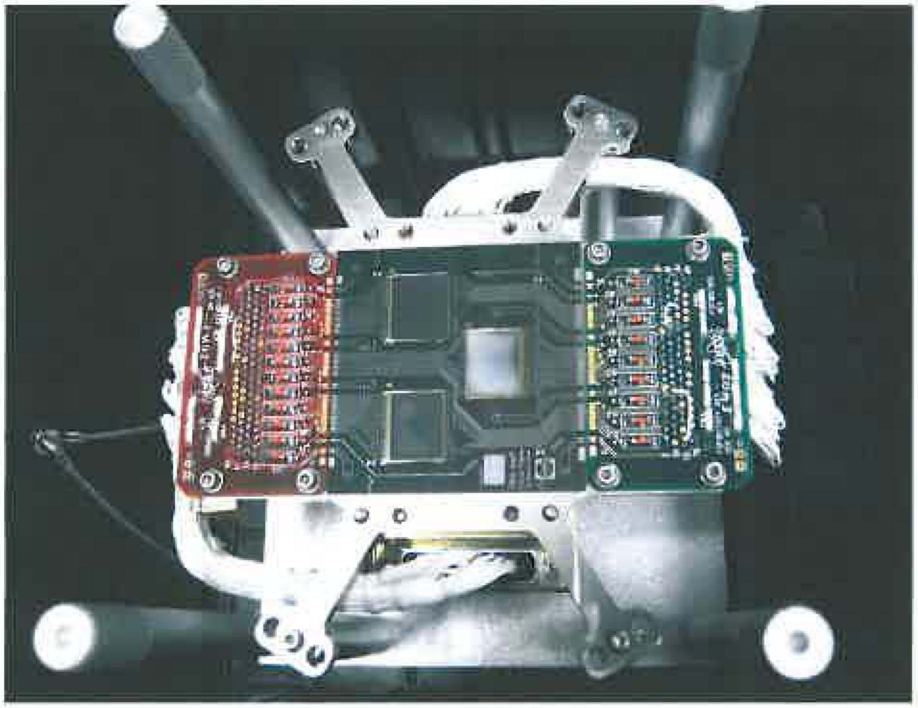
<u>QWIP</u> NEΔT (based on g-r, read noise only); measured ROIC read noise=300e

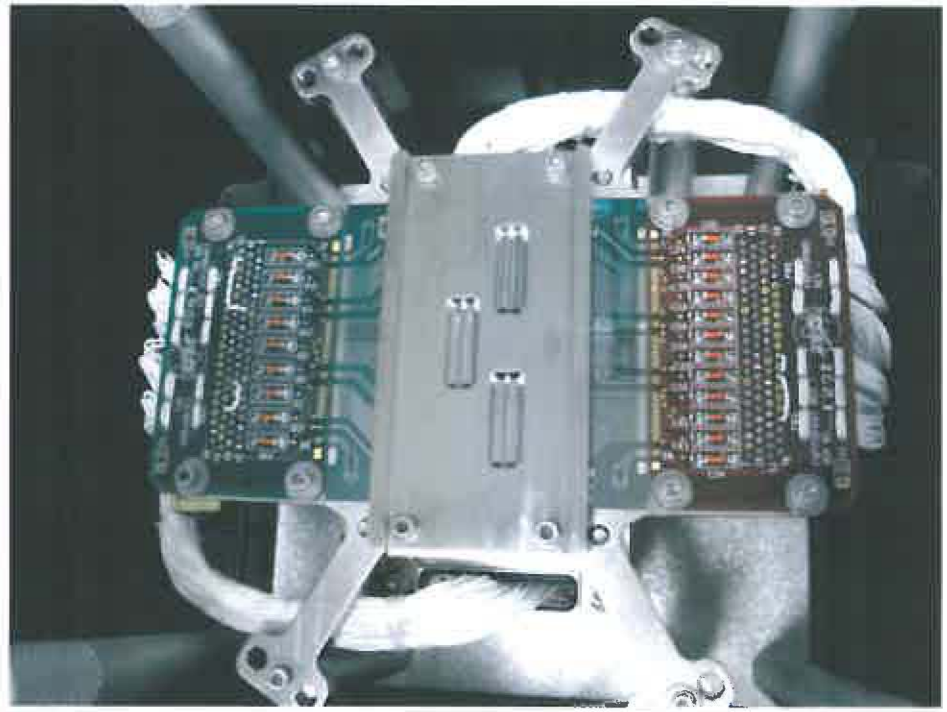
Grating QWIP:
NEΔT= 0.052K at 12.3μm; NEΔT= 0.0305K at peak λ (~11.2μm)

C-QWIP:
NEΔT= 0.074K at 12.3μm; NEΔT= 0.0374K at peak λ (~11.3μm)

Both devices meet TIRS specifications. Selection will be determined by system test results which include focal plane operating T, T stability and spectral uniformity.

TIRS Flight Performance Unit
(Engineering Test Unit)





Focal plane with 3 QWIP hybrids (2-QmagiQ, 1-ARL/GSFC)

Focal plane with filter assembly mounted over the QWIP arrays

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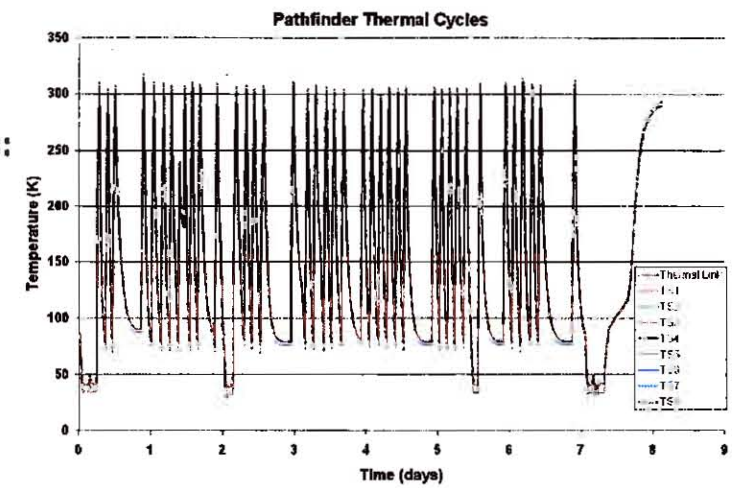
TIRS Technology Readiness Level (TRL)

There are 9 Technology Readiness Levels: TRL 1 is "Basic principles observed and reported; TRL 9 is "Actual system 'flight proven' through successful mission operation".

TRL 6 demonstration is the basis for acceptance into a NASA Space Flight mission "System/subsystem model or prototype demonstration in a relevant environment".

The TIRS Flight Performance Unit:All critical thermal interfaces on the TIRS FPA have been tested

- **All components and adhesives are thermally compatible with each other proven by test or high confidence by analysis**
- **Performed forty (40) thermal cycles from 300K to 77K**
- **Performed complete FPA vibration to LDCM qualification levels:**
  - **-Sine sweep, sine burst and random**



Sine Burst

Level:	15 G
Frequency:	20 Hz
Duration:	5 Cycles/min

- **Tested the Indigo 9803 to 35Krads total ionizing radiation dose (Co^{60})**
- **Tested the Indigo 9803 to a cumulative 63.3 MeV, TID = 20 krad(Si) and proton fluence = $1.5x10^{11}$ p/cm^2 .**

ALL TESTS WERE SUCCESSFULLY COMPLETED

Summary

- We have a unique opportunity to develop a QWIP-based earth observing instrument for one of the nations pre-eminent resources-the Landsat Program.
- The project is pursuing an extremely aggressive path to meet schedule.
- The collaborative and extremely interactive relationship between Goddard, the Army Research Lab, QmagiQ and our vendors is absolutely key to the success of this project.
- Much of the design and fabrication is based on Space Flight hardware developed for previous NASA missions (most notably the James Webb Space Telescope).
- All hardware has been designed and fabricated, current emphasis is on the QWIP development.

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